1. Agency Use Only *(Leave blank).*	2. Report Date. 1993	3. Report Type and Dates Covered. Final - Conference Proceedings

4. Title and Subtitle.
Expert Maintenance Advisor Development for Navy Shipboard Systems

5. Funding Numbers.
Program Element No. 256020N
Project No. 00101
Task No. 101
Accession No. DN257009
Work Unit No. 573511203

6. Author(s).
Harris, P. and R. Romalewski

7. Performing Organization Name(s) and Address(es).
Naval Research Laboratory
Ocanography Division
Stennis Space Center, MS 39529-5004

8. Performing Organization Report Number.
World Congress on Expert Systems, Final Program, Lisbon/Estoril, Portugal

9. Sponsoring/Monitoring Agency Name(s) and Address(es).
Naval Sea Systems Command
Washington, DC 20362-5104

10. Sponsoring/Monitoring Agency Report Number.
NRL/PP/7355--93-0009

11. Supplementary Notes.

12a. Distribution/Availability Statement.
Approved for public release; distribution is unlimited.

12b. Distribution Code.

13. Abstract *(Maximum 200 words).*

In the Navy's search to find a more cost-effective maintenance tool, the Naval Research Laboratory at Stennis Space Center, Mississippi developed an Expert Maintenance Advisor for the AN/USH-32(V) Signal Data Recorder-Reproducer Set. This analog tape recorder system is a high performance acoustic data recorder/reproducer set used in data acquisition and data processing. Its maintenance is complicated by multiple adjustments, their relationships, and lengthy calibration and checkout procedures. The Expert Maintenance Advisor is a reference aid which has expert knowledge and the complete technical manual (text and graphics) embedded in a PC-based computer that is portable and user friendly. This paper discusses its development, knowledge engineering process and maintenance diagnosis capability.

14. Subject Terms.
Expert systems; ASW scenarios; artificial intelligence; maintenance advisors

15. Number of Pages. 9

16. Price Code.

17. Security Classification of Report.	18. Security Classification of This Page.	19. Security Classification of Abstract.	20. Limitation of Abstract.
Unclassified	Unclassified	Unclassified	SAR

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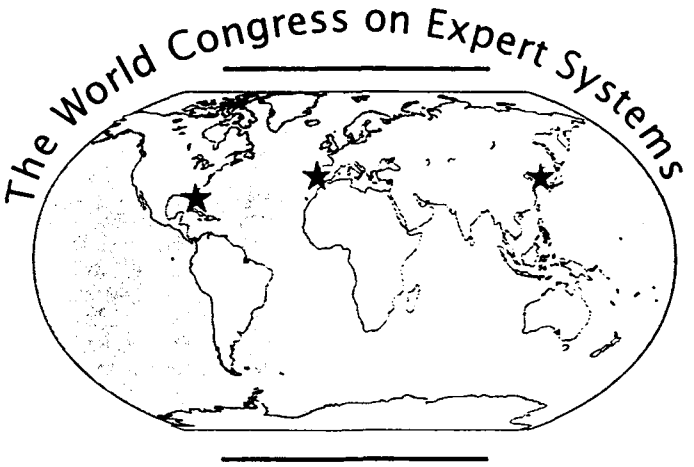

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Expert Maintenance Advisor Development For Navy Shipboard Systems

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ABSTRACT

In the Navy's search to find a more cost-effective maintenance tool, the Naval Research Laboratory at Stennis Space Center, Mississippi developed an Expert Maintenance Advisor for the AN/USH-32(V) Signal Data Recorder-Reproducer Set. This analog tape recorder system is a high performance acoustic data recorder/reproducer set used in data acquisition and data processing. Its maintenance is complicated by multiple adjustments, their relationships, and lengthy calibration and checkout procedures. The Expert Maintenance Advisor is a reference aid which has expert knowledge and the complete technical manual (text and graphics) embedded in a PC-based computer that is portable and user friendly. This paper discusses its development, knowledge engineering process and maintenance diagnosis capability.

Introduction

The Navy has numerous shipboard systems which require corrective/preventive maintenance. Sailors and in-service engineering agents (ISEA) from Navy field activities perform these maintenance tasks using paper technical manuals and the associated test equipment while in port or at sea. Four problems associated with performing these maintenance tasks are:

1) Personnel Availability
2) Labor Intensive Test and Checkout Procedures
3) Absence of System Test Tapes
4) Costs

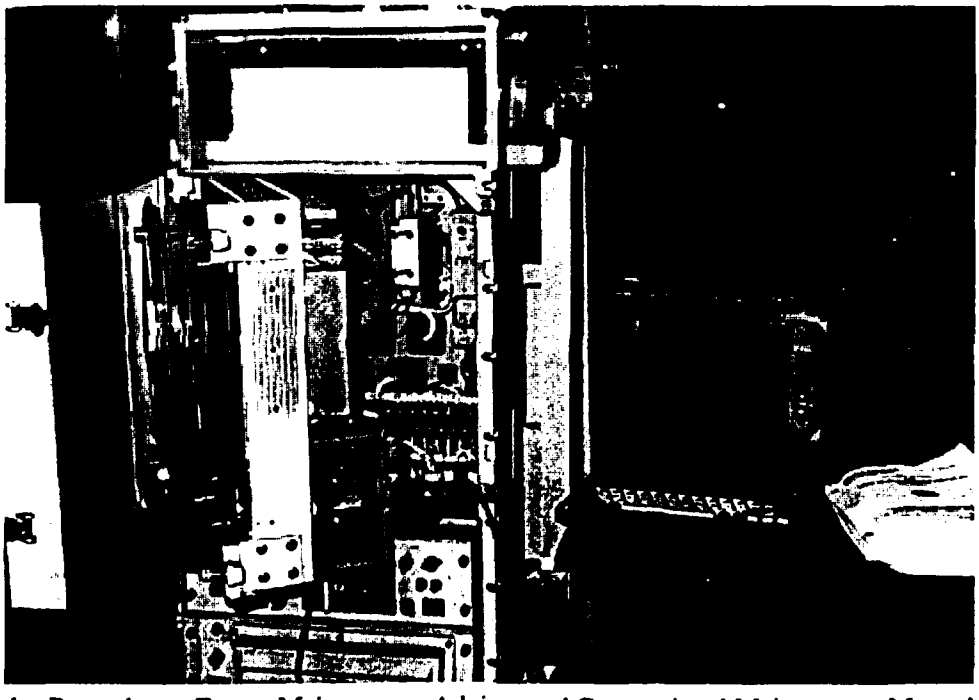

Figure 1. Recorder-Reproducer, Expert Maintenance Advisor and Conventional Maintenance Manuals.

The EMA was developed to best meet Navy needs and support fleet readiness requirements. It is a PC-based reference aid which uses embedded subject matter expert knowledge to assist sailors with maintenance related tasks and provides heuristics which increase rather than remove or replace theirability to maintain Navy systems in a fully operational status. This Expert Systems technology application not only reduces maintenance costs but increases maintenance personnel skill level and system diagnosis turnaround time. The EMA is an intelligent reference aid not an electronic technical manual or automated page turner.

The first Expert Systems technology application (Figure 1) was the AN/USH-32(V) Signal Data Recorder-Reproducer (SRRS). It is menu driven (Figure 2) and provides facilities for rule-based language input, debugging, editing and testing. The Expert Maintenance Advisor is most valuable to maintenance personnel during maintenance turn-on procedures, troubleshooting and system diagnostics. It uses embedded subject matter expertise to guide them through a logical sequence of maintenance actions by incorporating "tricks of the trade" and "rules of thumb" in a reference section. Indexing, hypertext and direct table access are features visible on all screen displays for instantaneous access to technical manual references and graphics. These features alone make the EMA a complete reference aid for rapid maintenance actions.

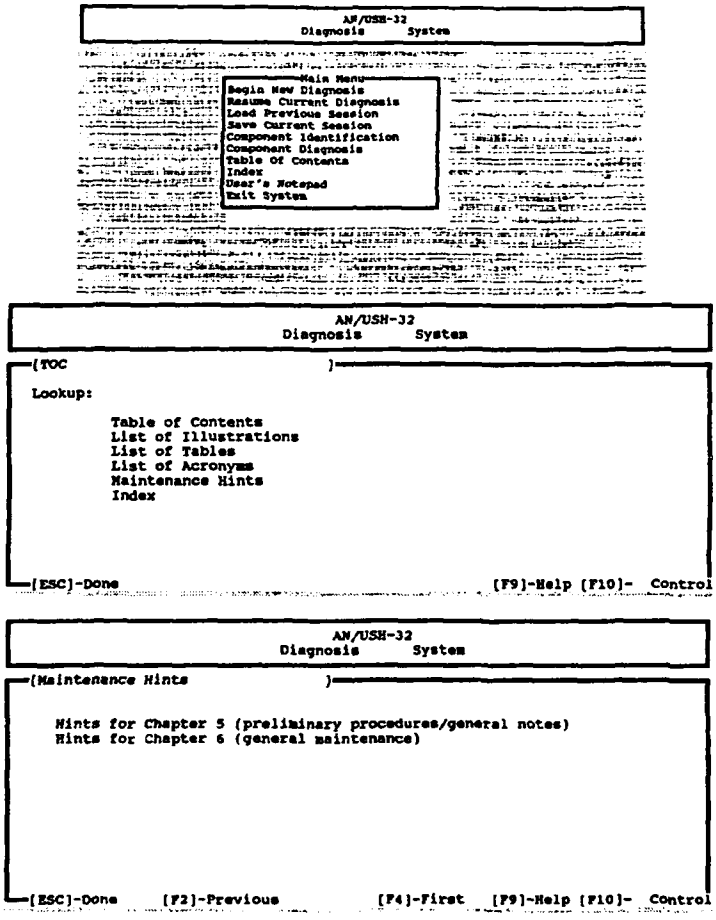

Figure 2. System Configuration

The system is hosted on a laptop computer running in a 4.01 or higher DOS environment. It requires a 120 MB hard drive and 4 MB of RAM which includes 3 MB extended RAM for storage and quick retrieval of textual data and graphics. Hypertext and highlighting features are included for all technical manual references during system diagnosis (AN/USH-32(V) Expert Maintenance Advisor User's Guide, 1992).

Expert Systems Development Approach

A rule-based language is used to develop and debug the EMA's knowledge. A maintainable rule-based language defines the encoded domain knowledge, which in turn is processed by an inference engine. (Alphonso, 1989) The expert system shell is written in a conventional programming language, C, which manipulates the knowledge with rules, facts, goals and a backward chaining inference mechanism. The heart of the system is embedded in a set of library routines. These routines are designed such that there is a close integration between the rule-based language and the source code, yet the two can be

developed independent of each other. A programmer can design the source code so that it uses the rule language to its fullest extent without knowing what rules are being used.

Library routines are callable from a conventional programming language to design, encode, debug and maintain knowledge. They manipulate the knowledge with an expert system shell independent of the conventional programming language. The static nature of the conventional programminglanguage and the dynamics of the knowledge base make development and implementation independently unique for the knowledge base and source code development process.

Knowledge Engineering

Simply acquiring expert knowledge isn't enough, the approach to knowledge engineering is the true success to knowledge base development. The EMA does use existing knowledge, the technical manual, to make the knowledge engineering productive. The maintenance procedure flow diagram was used as the foundation to build the knowledge base. It includes every fact in its original format from the technical manual. The knowledge acquisition sessions provided a mechanism to format the knowledge presentation, refine knowledge information, design and implement source code and test and validate the EMA performance. (Kearney, 1990)

The knowledge acquisition sessions were conducted with ISEA representatives at the Naval Undersea Warfare Center (NUWC) in Norfolk, Virginia using troubleshooting and corrective maintenance sections from the technical manuals as the knowledge presentation format. Knowledge is represented as a set of complex data structures which consists of pointers to a linked list of objects. The technical manual is the primary knowledge base development source. It includes the objects, their pointers and attributes in the form of rules, facts and goals which determine the optimal resolution to an EMA system diagnosis. The maintenance turn- on, corrective maintenance and troubleshooting procedures are enhanced by the availability of knowledge engineering acquisition input from subject matter experts. The knowledge engineering input is embedded in a helpful hints section to insure that the technical manual retains its originality. This knowledge engineering approach makes subject matter expertise readily available and easy to update.

Initial operational suitability tests were conducted at the NUWC and the Fleet AntiSubmarine Warfare Training Center Pacific (FLEASWTRACENPAC) to validate EMA Version 1 for fleet readiness. A supplemental fault isolation procedure to reduce in-fleet maintenance/alignment deficiencies is proposed for EMA Version 2. This proposed enhancement can be achieved with the development of a pre-recorded test tape. The pre-recorded test tape serves as an alignment tool for DIRECT/FM reproduce electronics and the capstan servo system. Test and alignment requirements can also be provided for the record electronics. Troubleshooting diagrams that perform true fault isolation and waveforms of actual properly adjusted signals at test points can be a part of the test/checkout procedure.

System Diagnosis Capability

The EMA's system diagnosis capabilities include:

1) Start To Finish Diagnosis
2) Specific Component Diagnosis
3) Save and Load Session Diagnosis

It can assist maintenance personnel with system maintenance from start to finish with or without previous knowledge of problem. In this diagnosis mode, the EMA relies on the sailor to observe and report the status of lamps, circuit breakers and motor movements to isolate the system fault. If the sailor suspects a problem in a specific component, the interactive troubleshooting and fault localization process can begin at that point in the logic diagram flow. Figure 3 shows an excerpt from the logic flow diagram and its source code rules. Interruptions or detail to other mission critical tasks may require that the sailor terminate an EMA session. If this happens, this session can be saved at that point and reloaded at the same point later. The addition of a Helpful Hints section gives sailors the benefit of having an expert by their side at all times in any system diagnosis mode. Appendix A is an example of a demonstration scenario using the EMA.

```
rule
if problem1a1 is not solved
and main_power_lamp is not illuminated
then text message2
and check is "f_5-2"
and problem1a is solved.

rule
if problem1a1 is not solved
and main_power_lamp is illuminated
and cooling_blower is not operating
then text message2
and check is "f_5-2"
and problem1a is solved.

rule
if problem1a1 is not solved
and main_power_lamp is illuminated
and cooling_blower is operating
and circuit_breaker_A2A8CB2 is trip
then say
"Troubleshoot +28 volt DC Logic &
 Indicator Power Distribution Circuit."
and check is "f_5-4"
and problem1a is solved.

rule
if problem1a1 is not solved
and main_power_lamp is illuminated
and cooling_blower is operating
and circuit_breaker_A2A8CB2 is not trip
and circuit_breaker_A2A8CB1 is trip
then say
"Troubleshoot +29 volt DC Logic &
 Indicator Power Distribution Circuit."
and check is "f_5-4"
and problem1a is solved.
```

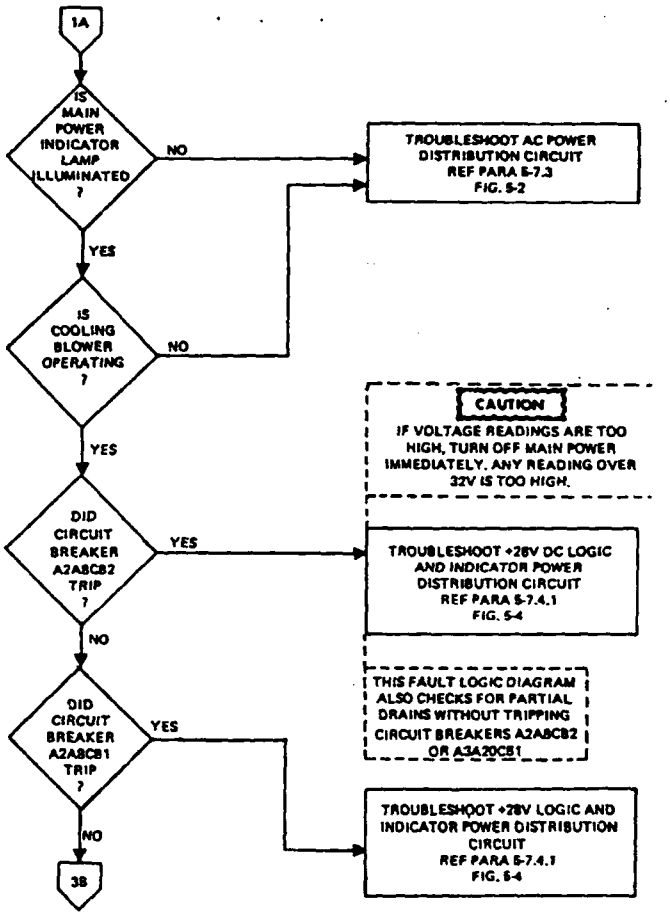

Figure 3. Troubleshooting Flow Chart and Rule Source Code

Summary

The Expert Maintenance Advisor makes a significant impact on the AN/USH-32's operational availability for data acquisition and data processing. It is an intelligent shipboard maintenance capability that provides on-line expert knowledge in a small portable package. Cost savings to the Navy in terms of time and service requests to Navy field activities and other commercial vendors will be substantial.

The Expert Maintenance Advisor has received numerous accolades during its debut in the training community. Several suggested improvement features from the training community were incorporated in Version 1 after visits with Naval personnel at the FLEASWTRACENPAC in San Diego, California. It was also exhibited at the First World Congress On Expert Systems held in Orlando, Florida, December, 1991. The Expert Maintenance Advisor saga continues while the Navy's new maintenance capability sets the pace as the "wave of the future" ashore and afloat.

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Technical Manual For Sonar Data Recorder-Reproducer Set AN/USH-32(V), Volume 2, SE314-GV-MMM-02A, Change A, 1 MAY 88

ACKNOWLEDGMENTS

The authors wish to express their sincere appreciation to Ms. Kathy Einwich for the desktop publishing and graphics support and Ms. Matilda Carter for her assistance in the Expert Maintenance Advisor graphic screen captures included in this paper.

This work was sponsored by the Program Executive Officer for Surface and Ship ASW Systems (PMO411).

APPENDIX A

AN/USH-32 Expert Maintenance Advisor Demonstration Scenario

This demonstration diagnoses a fault in the detection assembly and advises the sailor to replace the End-of-tape/ Beginning-of-tape (EOT/BOT) A2A2A3. It sequences through functional observations, checks voltage levels and provides screen text/graphics information to the sailor during maintenance. Text and graphic excerpts from the system demonstration are listed with the interactive response shown in **bold**.

New Diagnosis - Main menu selection

Not Turns - Indicates the response to capstans motion

Illuminated - Indicates the response to main power lamp illumination

Operating - Indicates the response to cooling blower operation

None - Indicates the response to tripped circuit breakers

28 Volts - Indicates the response to the voltage meter reading

20 Volts - Indicates the response to the voltage meter reading

5 Volts - Indicates the response to the voltage meter reading

Not 15 Volts - Indicates the response to the voltage meter reading

Return - Message to troubleshoot the +15 volt Transport Power Distribution Circuit

Not Corrected - The alignment procedure does not correct the fault. If the sailor needs further details, they are available on the screen in paragraph p_6-2-2. P_6-2-2 references figure f_6-1 which is also available on the screen. Thesescreen outputs are accessible using hypertext features.

15 Volts - Indicates the response to the voltage meter reading

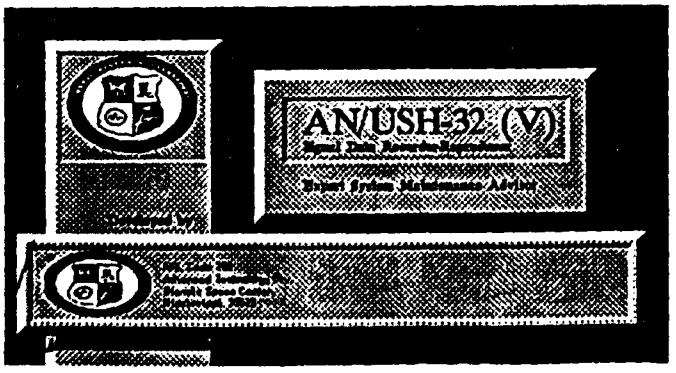
15 Volts - Indicates the response to the voltage meter reading

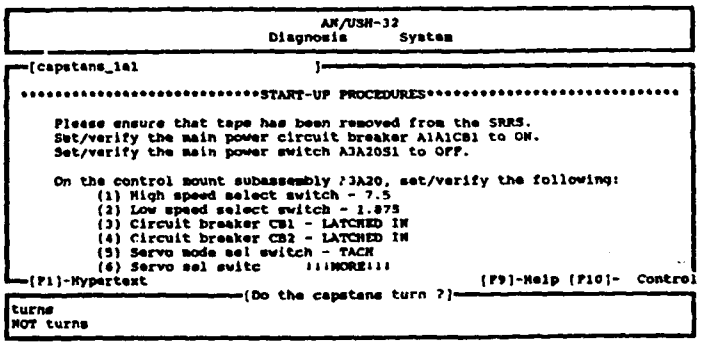
Not 15 Volts - Indicates the response to the voltage meter reading

15 Volts - Indicates the response to the voltage meter reading

Return - Advises the sailor to replace A2A2A3 detection assembly and provides a cross reference to the part number, manufacturer's address and installation/removal procedures

Return - Advises the sailor to perform the complete maintenance turn-on procedure to verify the SRRS's operational status





AN/USM-32
Diagnosis System

[main_power_lamp]

Please check the main power lamp to determine if it is illuminated.

[F1]-Hypertext [F9]-Help [F10]- Control

[Is the main power lamp illuminated?]

illuminated
NOT illuminated

AN/USM-32
Diagnosis System

[voltage_meter_5v]

Please set voltage check switch A3A20S14 to +5 volts. Now observe the voltage check meter to see if it indicates 5 volts.

[F1]-Hypertext [F9]-Help [F10]- Control

[Is the voltage meter 5v?]

5v
NOT 5v

AN/USM-32
Diagnosis System

[cooling_blower]

IS THE COOLING BLOWER OPERATING?

[F1]-Hypertext [F3]-Next [F9]-Help [F10]- Control

[Is the cooling blower operating?]

operating
NOT operating

AN/USM-32
Diagnosis System

[voltage_meter_15v_xport]

Please set voltage check switch A3A20S14 to +15 volts xport. Now observe the voltage check meter to see if it indicates 15 volts.

[F1]-Hypertext [F9]-Help [F10]- Control

[Is the voltage meter 15v?]

15v
NOT 15v

AN/USM-32
Diagnosis System

[circuit_breaker_tripped]

Please observe the status of the following circuit breakers to determine if they are tripped or not.

circuit breaker A1A8CB1
circuit breaker A1A8CB2
circuit breaker A1A8CB3
circuit breaker A1A8CB4

CAUTION!

If voltage readings are too high, turn off main power immediately. Any reading over 32 volts is considered to be too high.

[F1]-Hypertext [F9]-Help [F10]- Control

[Which circuit breaker is tripped?]

A2A8CB2
A2A8CB1
none

AN/USM-32
Diagnosis System

[Message]

Troubleshoot the +15 volt Transport Power Distribution Circuit.

AN/USM-32
Diagnosis System

[voltage_meter_28v]

Please set voltage check switch A3A20S14 to 28 volts. Now observe the voltage check meter to see if it indicates 28 volts.

[F1]-Hypertext [F9]-Help [F10]- Control

[Is the voltage meter 28v?]

28v
NOT 28v

AN/USM-32
Diagnosis System

[f_5-8_fault]

o Please perform the alignment procedure described in paragraph p_6-2-2.

IS THE FAULT CORRECTED?

[F1]-Hypertext [F9]-Help [F10]- Control

[Is the fault corrected?]

corrected
NOT corrected

AN/USM-32
Diagnosis System

[voltage_meter_20v_2b]

Please set voltage check switch A3A20S14 to +20 volts servo. Now observe the voltage check meter to see if it indicates 20 volts.

[F1]-Hypertext [F9]-Help [F10]- Control

[Is the voltage meter 20v?]

20v
NOT 20v

AN/USM-32
Diagnosis System

[p_6-2-2]

REGULATOR AND SERVO POWER AMPLIFIER. (See fig f_6-1.) To adjust the voltage regulator circuit on regulator and servo power amplifier A2A1, proceed as follows.

a. Secure the isolation mount safety latch. Open the dust cover and secure it in the open position with the safety latch. Load a reel of clean, degaussed tape.
b. Open transport assembly A2 to the fully open position and engage the transport safety latch.
c. Press the MAIN POWER switch to the ON position. Press the READY-LOAD switch to the READY position.
d. See fig f_6-1 and c !!!MORE!!! ultimeter between A2TP5

[F1]-Menu [F2]-Previous [F4]-First [F9]-Help [F10]- Control

[Is the fault corrected?]

corrected
NOT corrected

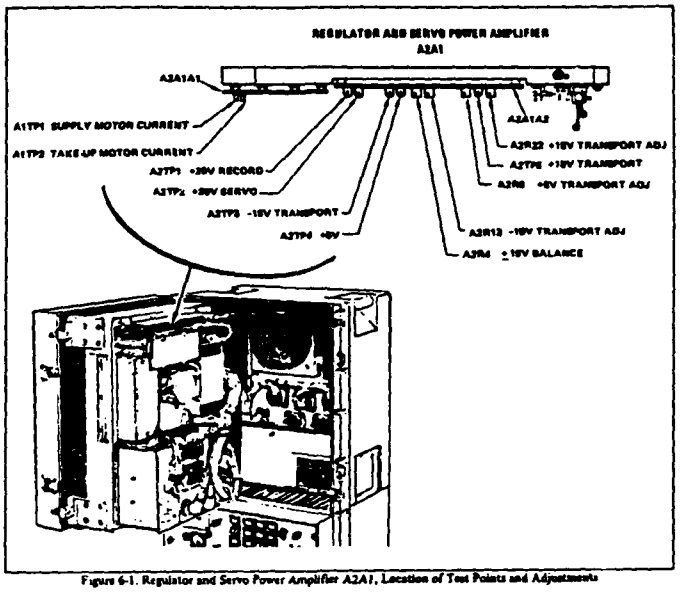


Figure 6-1. Regulator and Servo Power Amplifier A2A1, Location of Test Points and Adjustments

a. Secure the isolation mount safety latch. Open the dust cover and secure it in the open position with the safety latch.

b. Open the transport assembly A2 to the fully open position and engage the transport safety latch.

c. Open the hinged cover on the control mount A3.

d. Press the MAIN POWER switch to the ON position.

e. See figure 6-2 and connect the digital multimeter between TP1 (+) and TP2 (ground). Verify that the meter indicates +15 ±0.005 volts. If this reading is not obtained, adjust variable resistor R6.

f. Connect the digital multimeter between TP3 (-) and TP2 (ground). Verify that the meter indicates -15 ±0.005 volts. If this reading is not obtained, adjust variable resistor R11.

g. Connect the digital multimeter between TP1 (+) and TP2 (ground) and adjust variable resistor R6 to reduce the +15V by 50 millivolts (+14.950 ±0.005 volts).

h. Connect the digital multimeter to TP3 (-) and TP2 (ground) and verify that the reading has been reduced by 50 millivolts (-14.950 ±0.005 volts). If this reading is not obtained, adjust variable resistor R10 to obtain the necessary reduction in the reading.


```
                    AN/USH-32
                Diagnosis    System

[f_5-8_multimeter                ]

  o  Please press the main power switch to OFF.

  o  Disconnect connectors A2A8P7 from A2A2J2 on control logic assembly,
     A2A8P1 from A2A7AJ1J2 on record amplifier assembly and A1A3P4 from
     A2A8J2 on connector mounting bracket (SEE fig f_5-78).

  o  Connect a multimeter between TP5 (+15) and chassis qround on voltage
     regulator and servo power amplifier A2A1 (SEE fig f_6-1).

  o  Press the main power switch to ON.

     DOES THE MULTIMETER INDICATE +15 VOLTS DC?

[F1]-Hypertext                    [F9]-Help [F10]-  Control

[Is the multimeter +15v DC?]
+15v DC
NOT +15v DC
```

```
                    AN/USH-32
                Diagnosis    System

[f_5-8b_voltage_meter            ]

  o  Please press the main power switch to OFF.

  o  Reconnect A1A3P4 to A2A8J2 on connector mounting bracket.

  o  Press the main power switch back to ON.

     DOES THE VOLTAGE CHECK METER INDICATE 15 VOLTS?

[F1]-Hypertext                    [F9]-Help [F10]-  Control

[Is the voltage meter 15v?]
15v
NOT 15v
```

```
                    AN/USH-32
                Diagnosis    System

[f_5-8e_voltage_meter            ]

  o  Please press the main power switch to OFF.

  o  Then reconnect A2A8P7 to A2A2J2 on the control logic assembly.

  o  Press the main power switch back to ON.

     DOES THE VOLTAGE CHECK METER INDICATE 15 VOLTS?

[F1]-Hypertext                    [F9]-Help [F10]-  Control

[Is the voltage meter 15v?]
15v
NOT 15v
```

```
                    AN/USH-32
                Diagnosis    System
┌─[f_5-8f_voltage_meter          ]──────────────────────────────┐
│                                                               │
│  o  Please press the main power switch to OFF.                │
│                                                               │
│  o  Reconnect connector A2A7A31J2.                            │
│                                                               │
│  o  Remove EOT/BOT A2A2A3 from the control logic assembly A2A2│
│     (SEE figs fig f_6-37 and fig f_6-7).                      │
│                                                               │
│  o  Press the main power switch to ON.                        │
│                                                               │
│     DOES THE VOLTAGE CHECK METER INDICATE 15 VOLTS?           │
│                                                               │
│                                                               │
└─[F1]-Hypertext ──────────────[F9]-Help (F10)-  Control─────────┘
┌─[Is the voltage meter 15v?]──┐
│:5v                           │
│NOT 15v                       │
└──────────────────────────────┘
```

```
                    AN/USH-32
                Diagnosis    System
┌─[M_5-8-1                       ]──────────────────────────────┐
│                                                               │
│Please replace EOT/BOT A2A2A3 with a spare.                    │
│mfr 14028, part no. 541099                                     │
│PERFORM COMPLETE MAINTENANCE TURN-ON PROCEDURE.                │
│                                                               │
│                                                               │
│                                                               │
│                                                               │
│                                                               │
└─[ESC]-Done ──────────────────[F9]-Help (F10)-  Control─────────┘
```

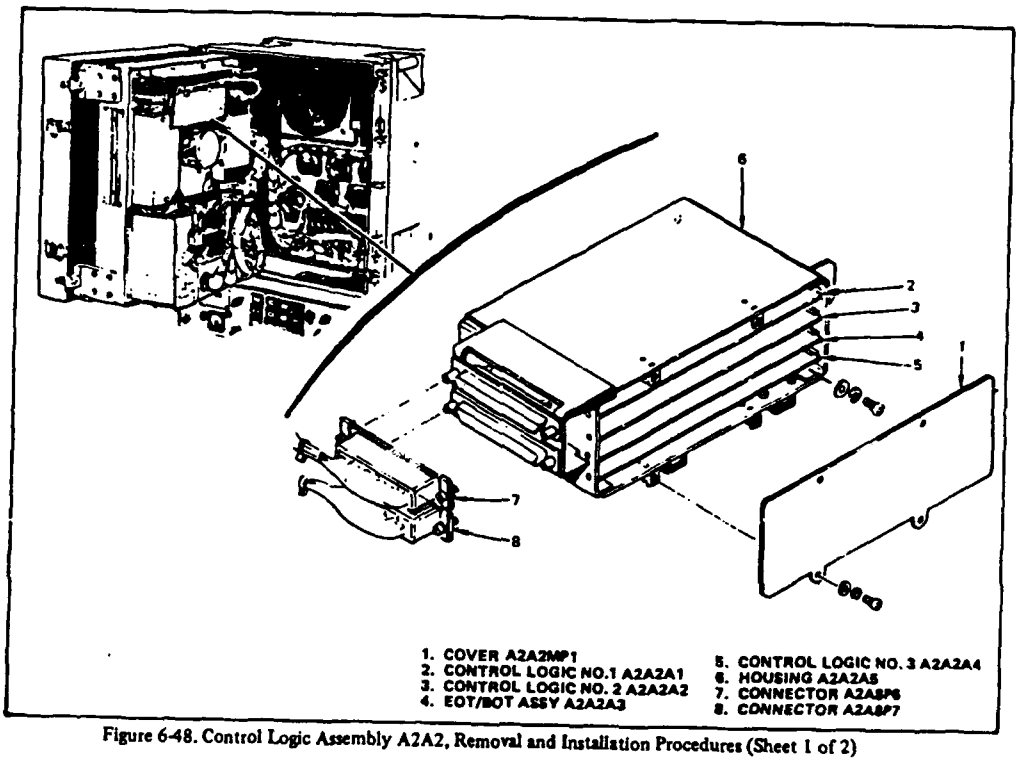


Figure 6-48. Control Logic Assembly A2A2, Removal and Installation Procedures (Sheet 1 of 2)

Table 7-2. Signal Data Recorder-Reproducer Set AN/USH-32(V)1 AN/USH-32(V)2 Part No. 541000-0001 or 541000-0002

Reference Designation	Notes	Name and Description	Figure Number (Item)
1A1A2A2A3	0	EOT/BOT Detection Assy mfr 14028, part no. 541099	6-48(4)

Table 7-5. List of Manufacturers

Mfr Code	Name and Address
14028	DATATAPE Incorporated A Kodak Company 360 Sierra Madre Villa Avenue Pasadena, CA 91109